EXPERIMENTAL RESEARCHES IN ELECTRICITY[1]

II.

THE experiments were made in a bell-jar, containing the terminals, which could be gradually exhausted after having been filled with air or other gas. One of the terminals was fixed to the bottom plate, the other could be adjusted to any distance from it by a rod sliding through a stuffing-box in the glass cover. The foot of the stand was insulated by a disk of ebonite, on which it stands. One such bell-jar is $9\frac{1}{4}$ inches (23·4 centims.) high, and $5\frac{7}{8}$ inches (14·9 centims.) in diameter; its cubical content, ascertained by covering the open ends with glass plates and filling with water from a graduated measure, was found to be 3,787 cub. centims.

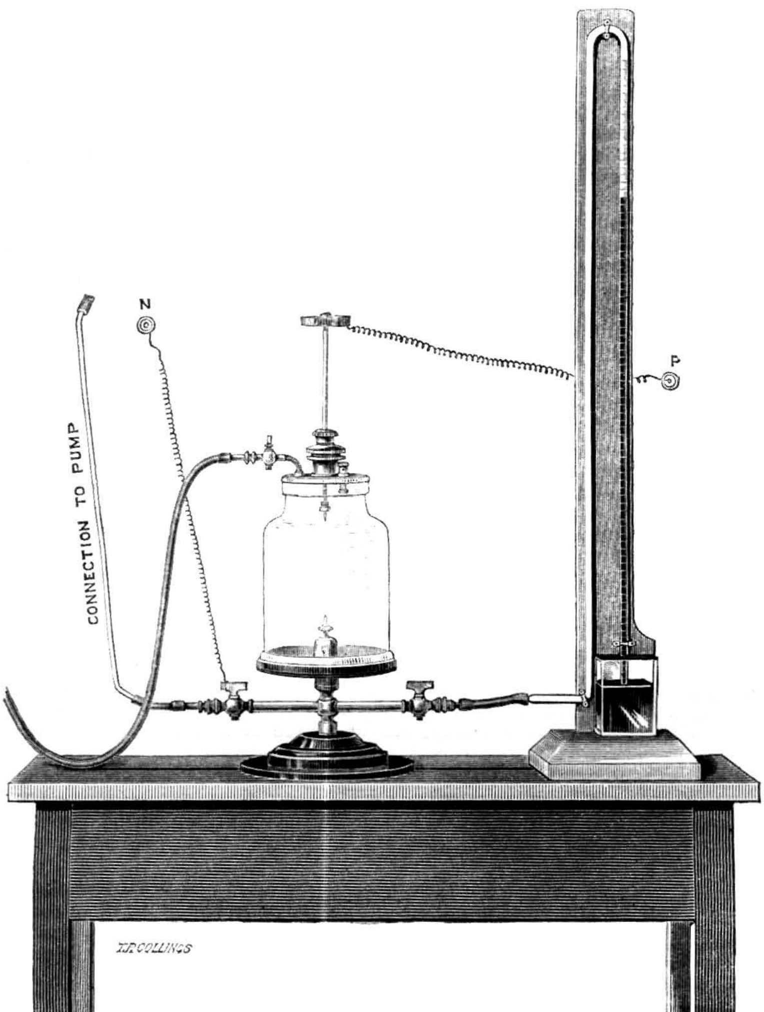

FIG. 3.

A remarkable phenomenon was observed on making connection between the terminals and the battery by means of the discharging key, namely, that within certain limits of pressure in the bell-jar a sudden expansion of the gas took place, and that as soon as the connection was broken the gas then as suddenly returned nearly, but not quite, to its original volume in consequence of a slight increase of temperature. The effect was exactly like that which would have been produced if an empty bladder had been suspended between the terminals and suddenly inflated and as suddenly emptied.[1]

The following experiment in rarefied air, at a pressure of 56 mm., at a temperature of 17°·5 C., will give an idea of the amount of instantaneous expansion which occurs when the terminals are connected with the poles of the battery of 11,000 cells, current 0·01102 **W**; the resistance of the bell-jar was reproduced by substituting 600,000 ohms wire resistance.

	mm.	M.
Distance of the terminals—the top one a point, the lower a disk—6 in.; pressure	56	... 73,684
On making contact the arc passed and the column of mercury was depressed ...	15·8	... 20,789
Pressure on connection ...	71·8	= 94,473

The increased was to the normal pressure in the ratio of 1·282 to 1; as the gas was kept at a constant volume, and supposing the expansion to be due to an increase of temperature, the pressure would vary as the absolute temperature,[2] therefore

$$\frac{T'}{T} = \frac{71 \cdot 8}{56} = 1 \cdot 282, \text{ whence}$$

$$T' = 1 \cdot 282 \times 291 \cdot 2 = 373^\circ \cdot 3 \text{ C.};$$

$$(373 \cdot 3 - 273 \cdot 7) = 99^\circ \cdot 6 \text{ C.},$$

the temperature of the bell-jar, and $(99 \cdot 6 - 17 \cdot 5) = 82^\circ \cdot 1$, the rise of temperature while the discharge was taking place. But the temperature of the bell-jar as determined by a thermometer inclosed in it with its bulb uppermost only rose 0°·64 C. per second, taking into account the rate of cooling. It is evident, therefore, that the increase of pressure cannot be ascribed to the instantaneous heating of the bell-jar 82° C.

Taking the dimensions of the arc from a photograph shown in the plate, Fig. 30, it was calculated that it must have attained the enormous temperature of 16,114° C., if the increase of pressure was really due to heat. It was found that platinum wires 0·001 inch in diameter supported in various parts of the arc, as shown in the plate, Fig. 30, were immediately fused; the temperature of the arc was therefore as high as the fusion-point of platinum, and possibly considerably higher.

If the whole of the heat evolved by a current of 0·01102 W, through a resistance of 600,000 ohms had been communicated to the air in the jar, weighing 0·339 grm., it would raise it 215°·6 C. in one second. It is known from direct experiment that this enormous evolution of heat was not communicated to any extent to the air in the bell-jar, because its temperature only increased about 0°·64 C. per second; the heat must consequently have escaped almost instantaneously by radiation. It is difficult consequently to realise the conjecture that the enormous dilatation which occurred instantaneously could have been caused by increase of temperature. And it points to its being produced by a projection or scattering of the molecules by electrification causing them to press outwards against the walls of the containing vessel, this pressure being distinct from the motion caused by heat.

[1] "Experimental Researches on the Electric Discharge with the Chloride of Silver Battery," by Warren De La Rue, M.A., D.C.L., F.R.S., and Hugo W. Müller, Ph.D., F.R.S. Continued from p. 153.

[1] De la Rive noticed that oscillations occurred in the mercury of a gauge attached to an exhausted tube as soon as the current passed.

[2] Absolute zero = 273·7 C., 273·7 + 17·5 = 291·2

The authors proceed to describe the appearance of the arc with terminals of various forms at different distances and with various pressures. It was found that the light emitted by different parts of the arc was not of the same intensity throughout, and that from the first there was a tendency to break up into distinct entities, as shown at A, B, C, D, E, F in the diagram, Fig. 4, which only indi-

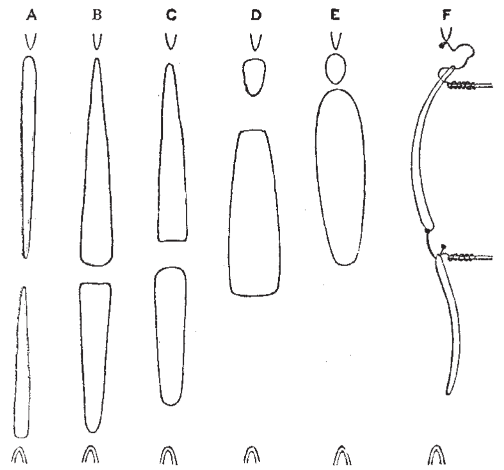

FIG. 4.

cates the central bright portion of the arc, this never quite reached the negative terminal, near which there was always the well-known dark discharge.

As the pressure was diminished the arc widened out, until at last the entire surface of the negative disk was covered with a luminous halo, and the discharge took up a stratified appearance.

The appearances presented by the arc in air, hydrogen, and carbonic acid are illustrated by copies of photographs and drawings in mezzotint, as shown in the Plate.

The arc in air between two points at various distances and pressures with a constant number of cells. Temp. 12·7 *C. The references are to the Plate*

11,000 cells, distance 0·54 inch, pressure atmospheric, current 0·02456 **W**; the total resistance of battery and arc was found to be 461,500 ohms, that of the arc, by substituting wire resistance, 27,550; whence the potential between the terminals was 657 cells. The appearance of the arc is shown in the plate, Fig. 20; it exhibits clearly the tendency to break up into luminous entities; the photograph of which this is a copy is nearly full size, and was obtained in twenty seconds. All the other copies of photographs are on a reduced scale. As the batteries were undergoing the annual overhauling, the number of cells, some being removed from time to time, was somewhat less in the following experiments, namely, 10,940.

Fig. 1, from a photograph obtained in 10 seconds.—Pressure atmospheric 748·6 mm., 985,000 **M**, distance 0·58 inch, current not observed, no depression of the mercury in the gauge was noticed; indeed, it will be seen that at the higher pressures the depression is generally less than at the lower, up to a certain point.

Fig. 2, from a photograph in 15 seconds.—Distance 0·58 × 2 = 1·16 inch, pressure 294·9 mm., 388,026 **M**, current 0·02881 **W**, depression 16 mm., total pressure 294·9 + 16 = 310·9; ratio of increased to normal pressure as 1·054 to 1. It will be observed that the central spindle has become bifurcated about midway.

Fig. 3, from a photograph in 15 seconds.—Distance × 3 = 1·74 inch, pressure 191·3 mm., 251,711 **M**, current 0·04060 **W**, depression 17 mm., total pressure 208·3 mm.; ratio of increased pressure 1·089. The bifurcation is apparent in this also.

Fig. 4, in which the central spindle is broken up into several luminosities.—Distance × 4 = 2·32 inches, pressure 142·6 mm., 187,631 **M**, current 0·04474 **W**, depression 19 mm., total pressure 161·6 mm.; ratio of increased pressure 1·133.

Fig. 5, from a photograph in 15 seconds; in this the central spindle is split up into bright entities connected by less bright portions.—Distance × 5 = 2·9 inches, pressure 112·6 mm. 148,157 **M**, current 0·03459 **W**, depression 19 mm., total pressure 131·6; ratio of increased pressure 1·169.

Fig. 6, from a photograph in 15 seconds. The luminous entities still seen, but are less marked.—Distance × 6 = 3·48 inches, pressure 99·4 mm., 130,789 **M**, current 0·03071 **W**, depression 21 mm., total pressure 120·4 mm.; ratio of increased pressure 1·211.

Fig. 7, from a photograph in 15 seconds.—Distance × 7 = 4·06 inches, pressure 85·9 mm., 113,026 **M**, current 0·03259 **W**, depression 22 mm., total pressure 107·9 mm.; ratio of increased pressure 1·256. The central spindle is divided into two luminosities, with a tendency to form a third near the negative.

Fig. 8, from a photograph in 15 seconds.—Distance × 8 = 4·64 inches, pressure 71·6 mm., 94,210 **M**, current 0·02693 **W**, depression 22 mm., total pressure 93·6 mm.; ratio of increased pressure 1·307. The central spindle nearly of the same character as Fig 7.

Fig. 9, from a photograph in 15 seconds.—Distance × 9 = 5·22 inches, pressure 65·5 mm., 86,184 **M**, current 0·02693 **W**, depression 22 mm., total pressure 87·5 mm.; ratio of increased pressure 1·336. The bright entities show a tendency to break up into less bright portions.

Fig. 10, from a photograph in 15 seconds.—Distance × 10 = 5·8 inches, pressure 64·4 mm., 84,737 **M**, current 0·03071 **W**, depression 20 mm., total pressure 84·4 mm.; ratio of increased pressure 1·310. The arc resembles that seen in Fig. 9.

The appearance of the arc between disks in hydrogen at the various pressures used in determining the potential necessary to produce a discharge, is represented in the plate, Figs. 11-19.

			M		Cells			Seconds
Fig.	11	at pressure of	18,684,	with	600,	from a photograph	taken in	50
,,	12	,,	58,684	,,	1200	,,	,,	50
,,	13	,,	141,974	,,	2400	,,	,,	50
,,	14	,,	252,368	,,	3600	,,	,,	50
,,	15	,,	386,316	,,	4800	,,	,,	20
,,	16	,,	558,816	,,	6300	,,	,,	4
,,	17	,,	558,816	,,	6300	,,	,,	1
,,	18	,,	651,316	,,	7760	,,	,,	5
,,	19	,,	1,008,421	,,	10,920	,,	,,	5

The arc in hydrogen between two points. Temp. 16°·2 C., 10,940 *cells*

Distance 0·75 inch, pressure 745 mm., 980,263 **M**, current 0·01575 **W**, the appearance is represented in the plate, Figs. 21 and 22, the first copied from a photograph obtained in 5 seconds, the second in 15 seconds. The central spindle breaks into a brush-like form towards the negative, there is then a dark interval between it and the glow on the negative.

Fig. 26, from a drawing.—Distance 0·9 inch, pressure 745 mm., 980,263 **M**, the discharge passed intermittently, so that the current could not be read off on the galvanometer. The appearance is represented full size.

Figs. 23, 27, 28.—Distance 0·9 × 2, 1·8 inch, pressure 385·6 mm., 507,368 **M**, current 0·01575 **W**, depression 14 mm., total pressure 399·6 mm., ratio of increased pressure 1·04. Fig. 23 is from a photograph in 13 seconds. The distance between the brush-like termination of the central spindle and the glow on the negative has relatively increased. Figs. 27 and 28 are other representations copied from drawings.

Fig. 24, from a photograph in 15 seconds.—Distance × 3, 2·7 inches, pressure 317·8 mm., 418,158 **M**, current 0·00580 **W**, depression 13 mm., total pressure 330·8 mm.,

ratio of increased pressure 1·04. The central spindle relatively still shorter. At times only the terminals were illuminated, but sometimes strata formed on the positive terminal. Fig. 29 is another representation copied from a drawing.

Fig. 25.—Distance × 4, 3·6 inches, pressure 170·5 mm., 224,342 **M**, 6300 cells, current not measured. The central spindle has decreased relatively still more.

Fig. 34, Distance × 7, 6·3 inches, pressure 3 mm., 3947 **M**, 1200 cells, the bottom point positive current 0·03896 **W**, a splendid stratification, though somewhat unsteady; the figure partly copied from a photograph, partly from drawings. It was thought at first that well-defined strata would not be formed in a jar of such large diameter with the quantity of current at disposal, but this experiment shows that this conjecture was unfounded. The negative glow completely fills the neck of the jar.

Fig. 31.—Distance 6·3 inches, pressure 2·4 mm., 3158 **M**, 1200 cells, current 0·02728 **W**, a very steady stratification when the bottom point was positive; this curious stratification completely overlapped the whole surface of the bottom point and the brass holder, as if pushed back by a force emanating from the negative, the glow around the negative completely filled the upper portion of the jar.

An inner tube was now inserted in the bell-jar in order to ascertain whether the contraction of the space surrounding the discharge would have any effect on the production of strata. A number of holes had been drilled in opposite sides of the tube, which is 8 inches long and 1·8 inch in diameter. These holes were drilled with the object of straining very fine platinum wires across at different heights for ascertaining the temperature of the arc at these positions, but in the experiments about to be described there were no wires.

The bell-jar was refilled with hydrogen and exhausted; distance of points 6·3 inches, pressure 2 mm., 2,632 **M**, 2,400 cells; when the top point was positive there was a production of ordinary strata resembling (Fig. 32). But when the bottom was positive a very remarkable phenomenon was observed, namely, the protrusion of strata through the small holes, $\frac{1}{8}$th inch in diameter, in the walls of the inner tube, this being accompanied by an overpouring of negative discharge above the top of it (Fig. 33). It seemed as if the positive discharge sought a complete neutralisation with negative electricity beyond the confines of the tube, the area of which was too small to permit of complete relief. The close confinement of the discharge at the bottom end of the tube which rests on the glass plate of the pump may account for the non-oozing out of strata through the holes when the top point was positive.

Some gas let in, pressure 4 mm., 5,263 **M**, 2,400 cells, current 0·15470 **W**, a well-defined stratification occurred when the bottom point was negative, but no oozing out through the holes in the tube, Fig. 32.

In order to prosecute their experiments in a vessel of still greater capacity, the authors had constructed a larger jar with a neck at each end, or more properly speaking, perhaps, a tube supported horizontally on ebonite crutches. It is 37 inches long and $5\frac{13}{16}$ inches in diameter, its cubical content was found to be 14,435 cub. centims., or 3·8 times that of the bell-jar employed in the experiments on the electric arc. The tube is shown in Fig. 5.

The experiments with this tube will necessarily occupy a considerable period, partly on account of the long time it takes to exhaust it after each set, partly on account of the variety of experiments it is intended to make with it; consequently they describe only a few of the first results hitherto obtained.

For Example in Air

Pressure 3 mm., 3,947 **M**, 6,300 cells. Two luminosities were formed, the ring negative being surrounded with a nebulosity which completely filled the end of the tube. The tube glowed brilliantly with a blue fluorescent light, which proved to have great actinic power. A dry-plate photograph obtained in five seconds records a very curious phenomenon, namely, that the outer boundary of the

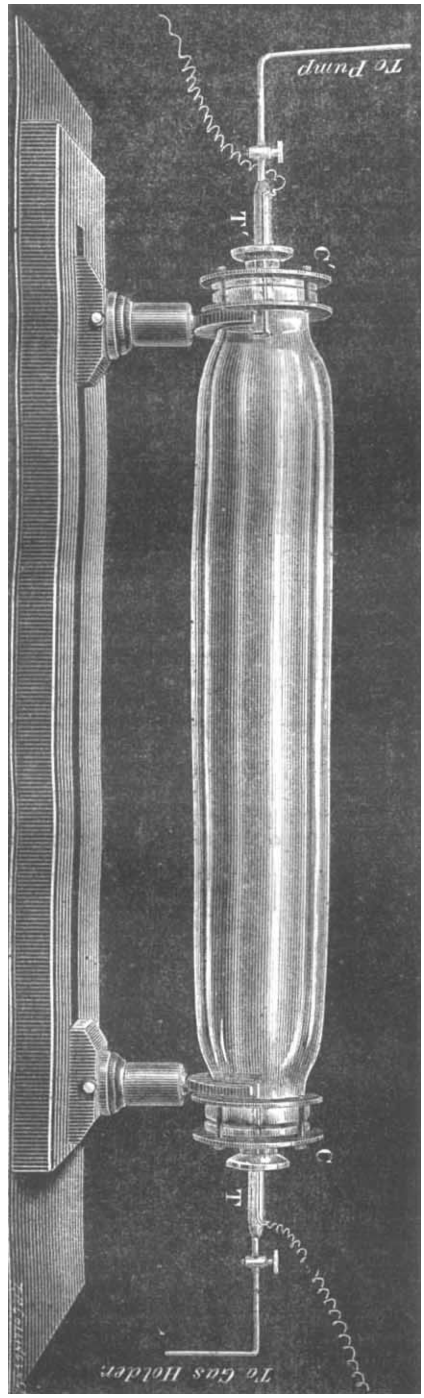

Fig. 5.

luminosity appears *darker* than the tube (Fig. 35). It is to be remarked that while the discharge was reddish (nitrogen), the fluorescence of the tube was blue; the effect appears to be due to the absorption of a portion of the fluorescent light emanating from the back of the

tube in passing through the red luminosity. The effect was quite unexpected, and it was thought at first that it might have arisen from some peculiarity in the development of the dry plate; it was not therefore until the result had been confirmed by other photographs that they ventured on the explanation above given.

A few experiments were made with hydrogen in this same tube; and the appearances observed are shown in Fig. 6, A B C.

Pressure 22 mm., 28,948 **M**, 11,000 cells, current 0·01412 **W**. The glow on negative extended to three-eighths of an inch, a spear-head luminosity on the positive wire, to which it was attached by a very bright wire-like stem not greater in diameter than the terminal, A (Fig. 6).

Pressure 15 mm., 19,737 **M**, 11,000 cells, current 0·03071 **W**. A spindle-shaped luminosity at the positive about $1\frac{1}{2}$ inch long, and the negative ring completely surrounded with a glow which had increased considerably since A. After a short time the spindle on the positive lengthened out and nearly reached the negative, hugging the underside of the tube as in B (Fig. 6). It was not sensitive to the approach of the finger, although close to the glass; 6,300 cells produced the same phenomena.

Pressure 4 mm., 5,263 **M**, 6,300 cells, current 0·03459 **W**. The discharge in the latter case was partially stratified, C.

The paper closes with the following conclusions:—

1. *For all gases there is a minimum pressure which offers the least resistance to the passage of an electric discharge. After the minimum has been reached, the resistance to a discharge rapidly increases as the pressure of the medium decreases.* With hydrogen the minimum is 0·64 mm., 842 **M**; at 0·002 mm., 3 **M**, it is as great as at 35 mm., 46,000 **M**.

2. *There is neither condensation nor dilatation of a gaseous medium in contiguity with charged terminals.*

3. *When the discharge takes place there is a sudden dilatation of the medium in addition to, and distinct from, that caused by heat. This dilatation ceases instantaneously when the discharge ceases.*

4. *The potential necessary to produce a discharge between parallel flat surfaces at a constant distance and various pressures, or at a constant pressure and various distances, may be represented by hyperbolic curves. The resistance of the discharge between parallel flat surfaces being as the number of molecules intervening between them.*

5. *This law does not hold with regard to points. In Part I. it has been shown that the potential necessary to produce a discharge at the atmospheric pressure and various distances is as the square root of the distances, while with a constant potential and various distances, the pressure has to be diminished in a greater ratio than that of the increase of distance in order to permit a discharge to take place.*

6. *The electric arc and the stratified discharge in vacuum tubes are modifications of the same phenomenon.*

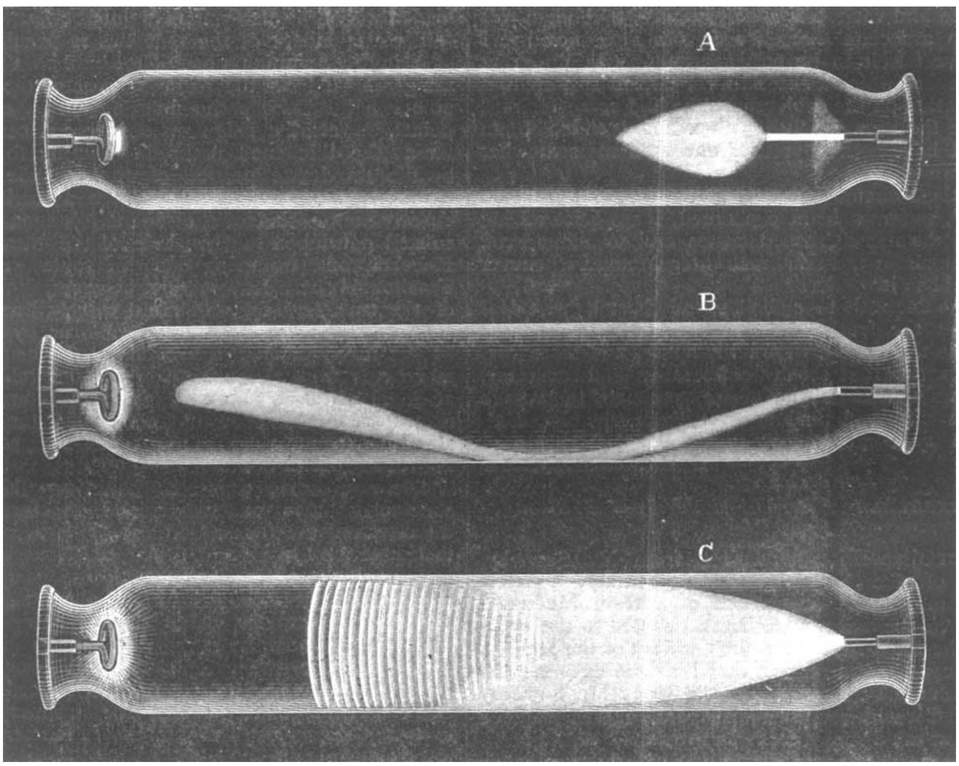

FIG. 6.

Lastly, the authors say:—

"We have again pleasure in thanking Prof. Stokes for his much-valued advice during the course of our investigations. To our assistant, Mr. Fram, we are indebted for his able co-operation; and we have to thank Mr. H. Reynolds for his aid and skill in taking photographs."

THE NEW FRESHWATER JELLY FISH

WE have received the following communications on this subject:—

The Freshwater Medusa

WHEN I last week sent you an account of the new genus of freshwater Medusæ, to which I gave the name Craspedacustes, I was not aware that Prof. Allman had prepared, or even that he was intending to prepare, an account of the same animal for the Linnean Society's